Discharge based EUV Sources for Metrology

Klaus Bergmann

EUV Source Workshop, October,9th, Dublin, Ireland

© Fraunhofer ILT

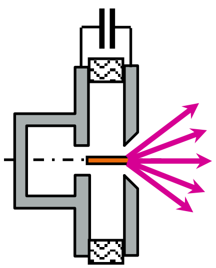
Fraunhofer
ILT

Overview

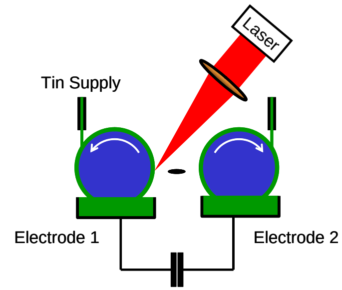
- Introduction
- Technology and current status of HCT sources at ILT
- Brilliance scaling for 13.5 nm
- Conclusions

© Fraunhofer ILT

History of EUV sources at ILT



AIXUV EUV-Technology

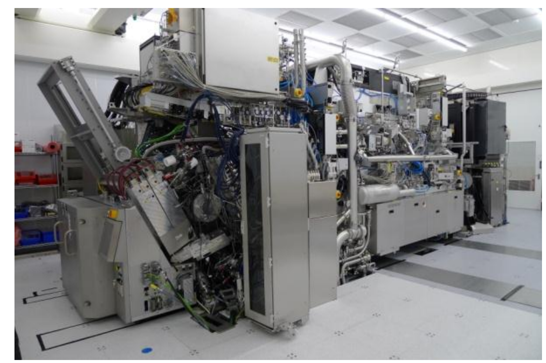


PHILIPS

year 1997 2001 2003 2006 2011

Fraunhofer ILT

PHILIPS



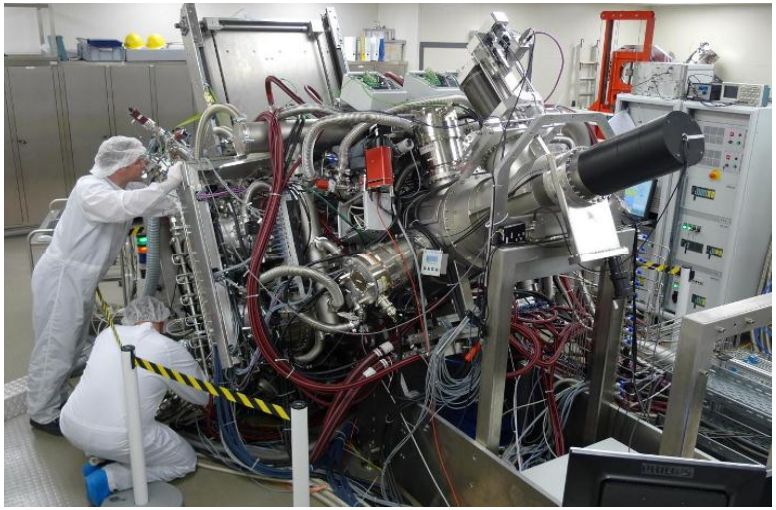
XTREME technologies USHIO GROUP

© Fraunhofer ILT

Fraunhofer ILT

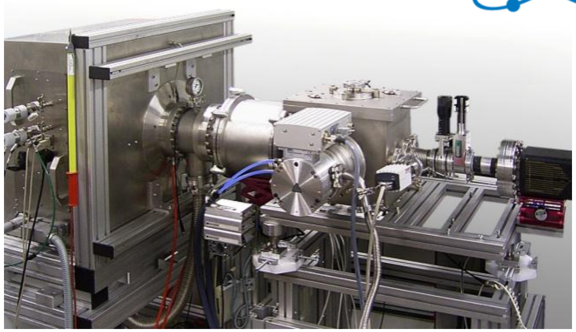
Current XUV activities at ILT

- Development of sources for EUV lithography based on tin vacuum arc (together with Xtreme)
- Sources for metrology in the range soft x-ray and EUV
- XUV-Applications (Support of TOS, RWTH Aachen University)

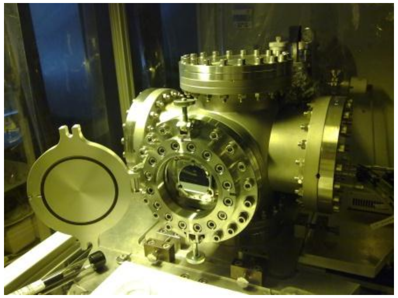


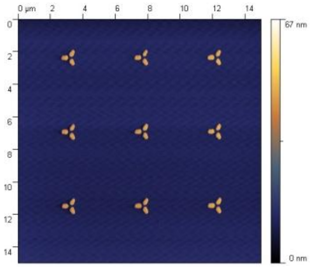
EUVL source development

X-ray microscopy



Interference lithography

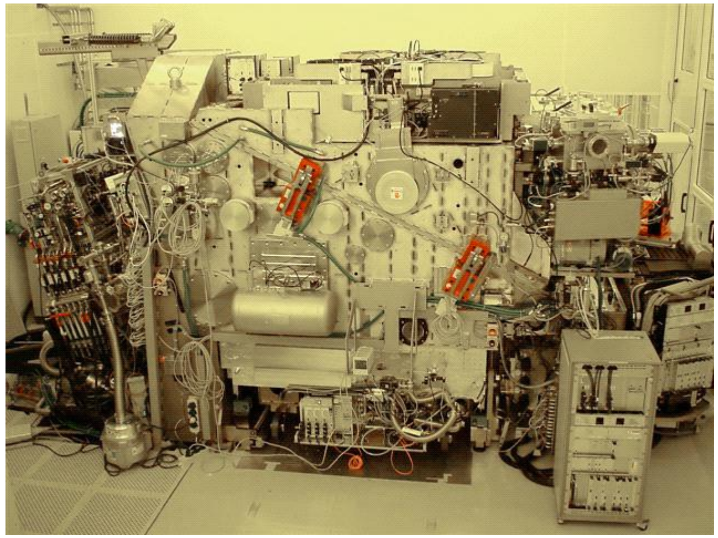




© Fraunhofer ILT

Technical base: Philips HCT source

Philips Xenon Source



ASML α-demo Tool

- HCT principle was patented by ILT
- collaboration on power scaling for use as EUVL source
- source delivered first light in ASML α-demo tool
- currently used in the field as metrology source (mirror contamination, optics characterization)

© Fraunhofer ILT

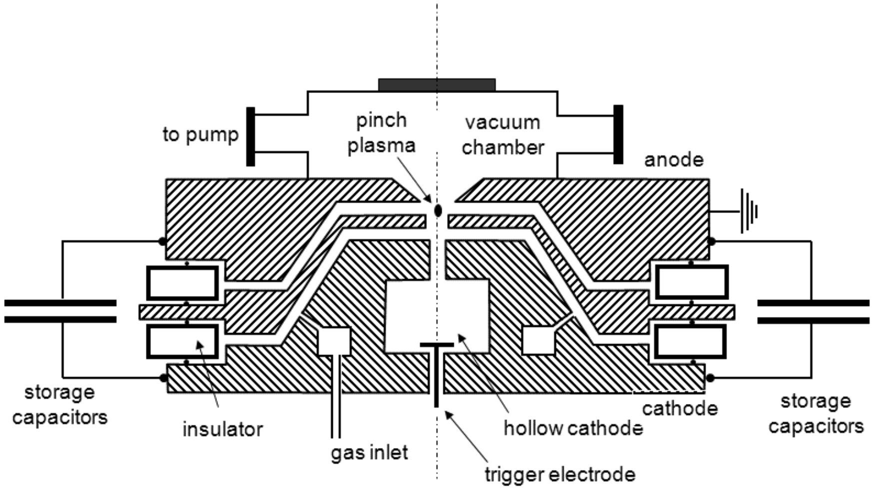
Next Generation Source at Fraunhofer ILT

- technical base is the HCT source developed with Philips EUV
- new system allows for higher input power and pulse energy
- simplified and more compact source head design
- emission in the soft x-ray to extreme ultraviolet range
- increased electrode lifetime

© Fraunhofer ILT

Fraunhofer ILT

Technical concept



Scheme of electrode system

- max. input power: 25 kW
- max. pulse energy: 20 J
- emission at 13.5nm: >50 W/(2πsr 2%b.w.)
- typical plasma length: 3-5 mm
- accessible collection angle: >80°

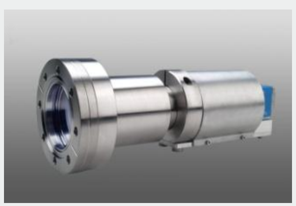
© Fraunhofer ILT

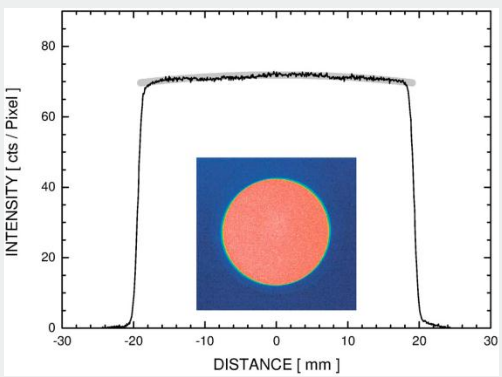
Selected examples of applications (1)

Absolute calibration of EUV diagnostics

Inband Energy Monitor

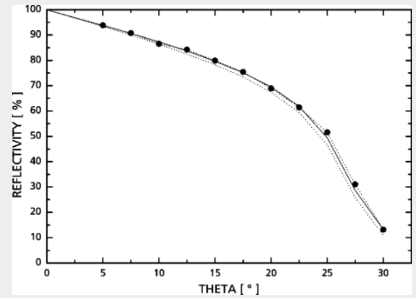
Inband Screen Tool

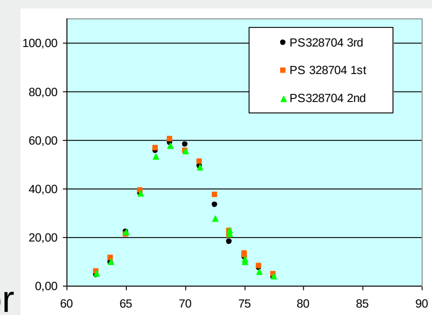




Gracing / Normal Incidence Reflectometer

Ru-Mirror





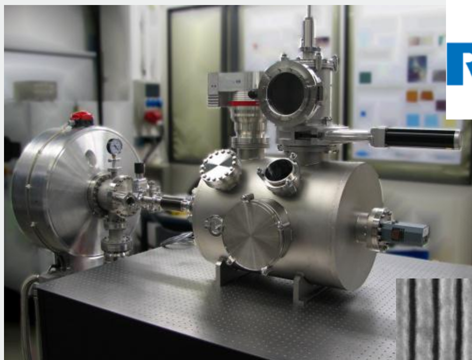
ML-Mirror

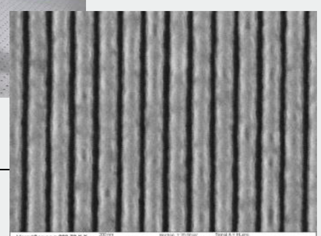
© Fraunhofer ILT

Fraunhofer ILT

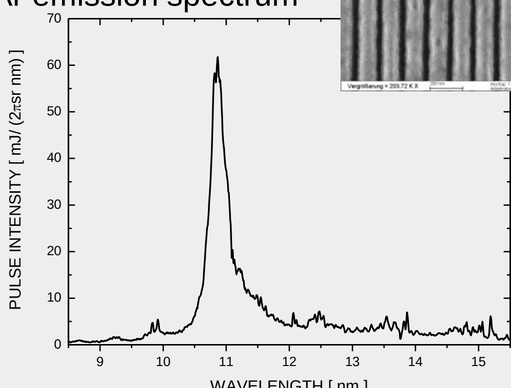
Selected examples of applications (2)

Interference Lithography (11 nm)



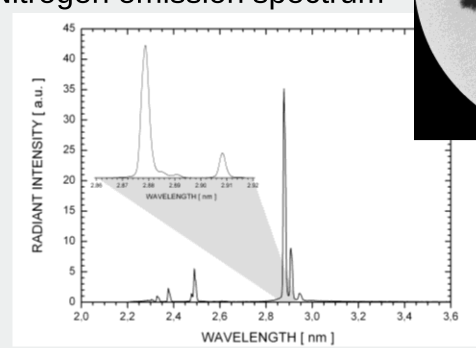


Xe/Ar emission spectrum



X-Ray Microscopy (2.9 nm)

Nitrogen emission spectrum

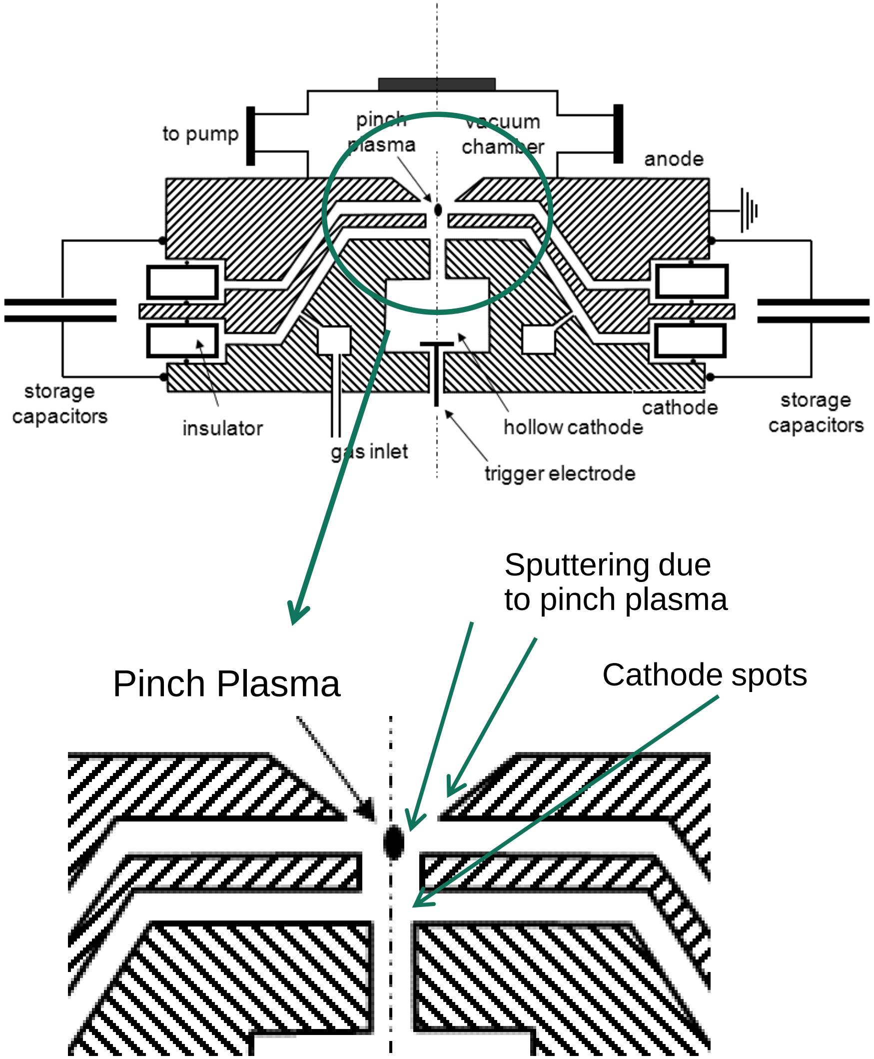


PbS nanocrystals for solar cells

© Fraunhofer ILT

Progress in Electrode lifetime

- erosion due to sputtering and cathode spots
- most critical consumable is cathode
- intermediate plate allows for reducing the influence of cathode erosion
- improvement by use of other metal
- envisioned interval for exchange of electrodes is 1Gshot



Cathode after 100 Mshot

Molybdenum

Metal with higher melting point

P:<ordner>name.ppt

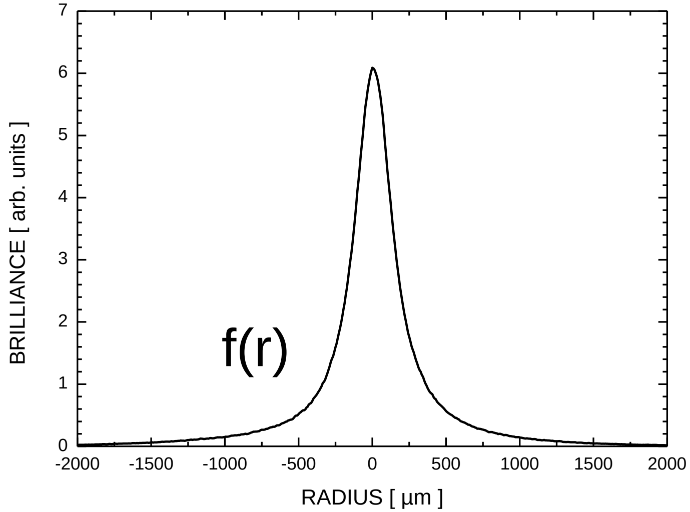
© Fraunhofer ILT

Fraunhofer ILT

How do we measure "Peak Brilliance"

Emission profile ($r_{1/2}$, ζ)

pinhole camera
+ Zr coated silicon nitride window



f(r=0) = 1.0

$$\zeta = \frac{2\int_0^\infty f(r)\,r\,dr}{r_{1/2}^2}$$

Inband power ($CE_{13.5nm}$)

calibrated energy monitor

f : repetition rate

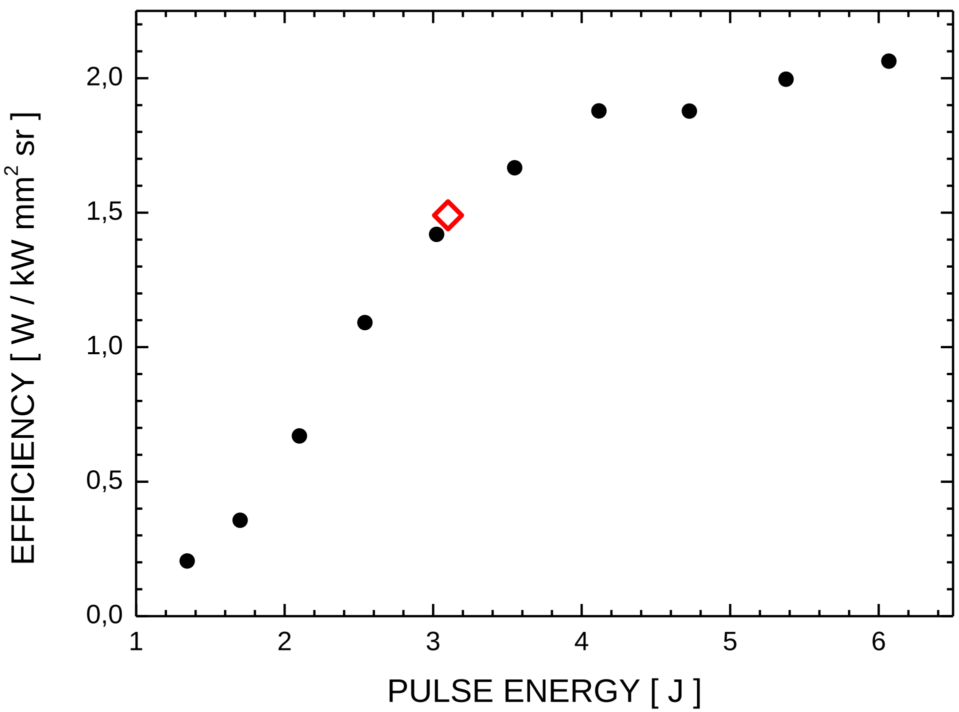
E_{in} : electrical pulse energy

$$\boxed{L_{peak} = \frac{f\,E_{in}\,CE_{13.5nm}}{\zeta\,\pi\,r_{1/2}^2}}$$

© Fraunhofer ILT

Fraunhofer ILT

Parameter studies (1): Brilliance Efficiency

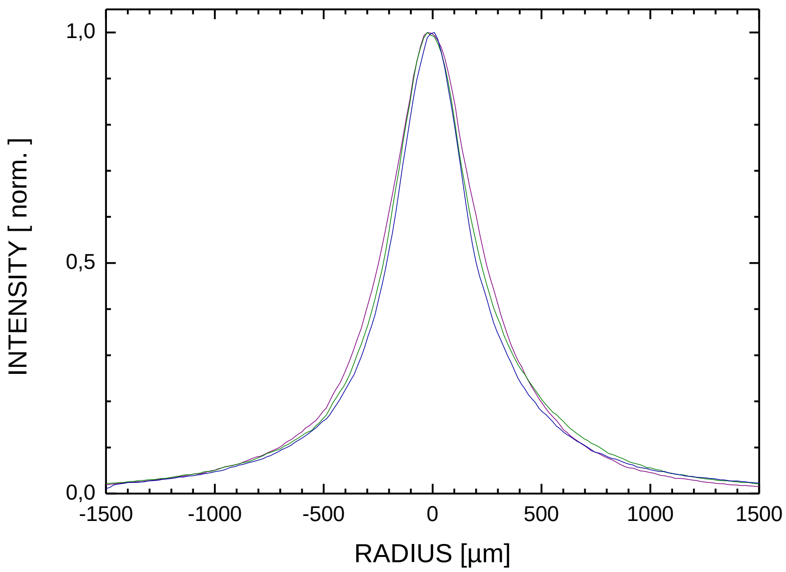


- peak brilliance at 300 Hz operation
- red rhomb for old system at 8.7 kW
- demonstrated 2.0 W/(kW mm^2 sr) at a pulse energy of 6.1 J

© Fraunhofer ILT

Parameter studies (2): Variation of pulse energy

Normalized profiles for different energies



- peak brilliance at 1000 Hz operation
- low variation of profile coefficients over wide range of pulse energies

E_{in} / J	$r_{1/2}$ / µm	ζ	$\zeta * r_{1/2}^2$/ mm^2
2.3	269	2.1	0.15
3.1	236	3.2	0.18
4.0	244	3.7	0.22
4.9	228	4.2	0.22
5.9	232	4.3	0.23
6.6	225	4.3	0.22
7.6	218	4.4	0.21
8.4	225	4.5	0.23

Brilliance efficiencies:

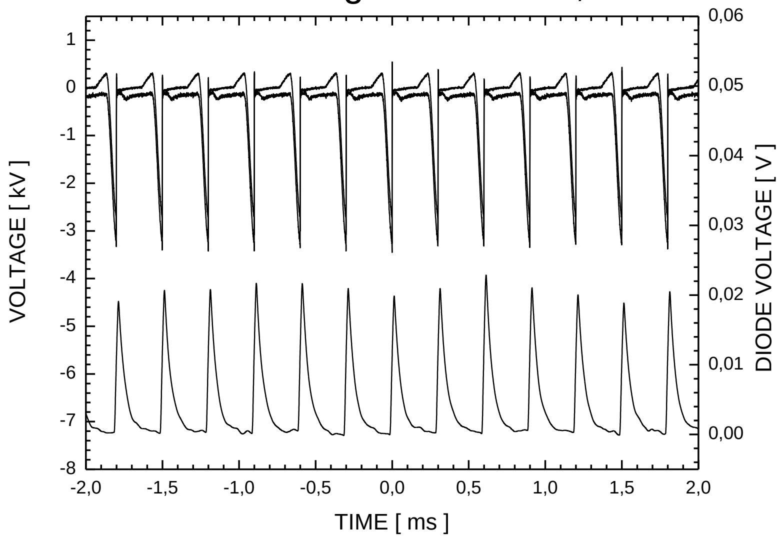
0.9 – 1.4 W/kWmm^{2}sr

© Fraunhofer ILT

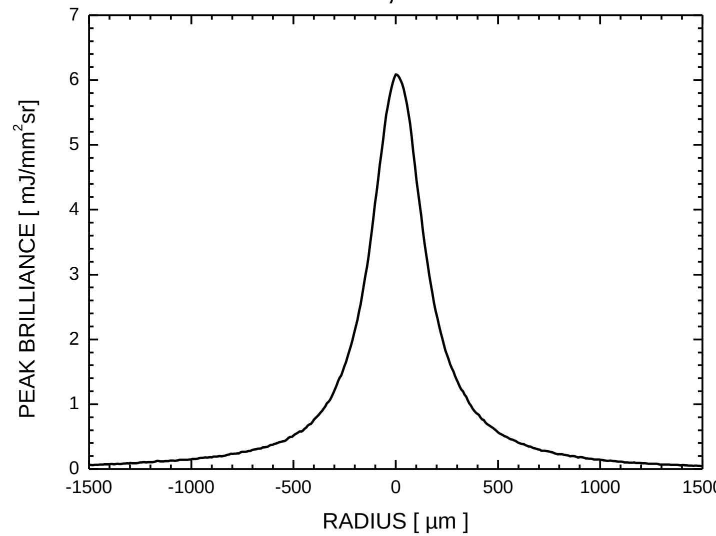
Fraunhofer ILT

Demonstration of 21 W/(mm²sr)

Diode and voltage for 3.3 kHz, 6.0J



Profile for 3.3 kHz, 6.0J



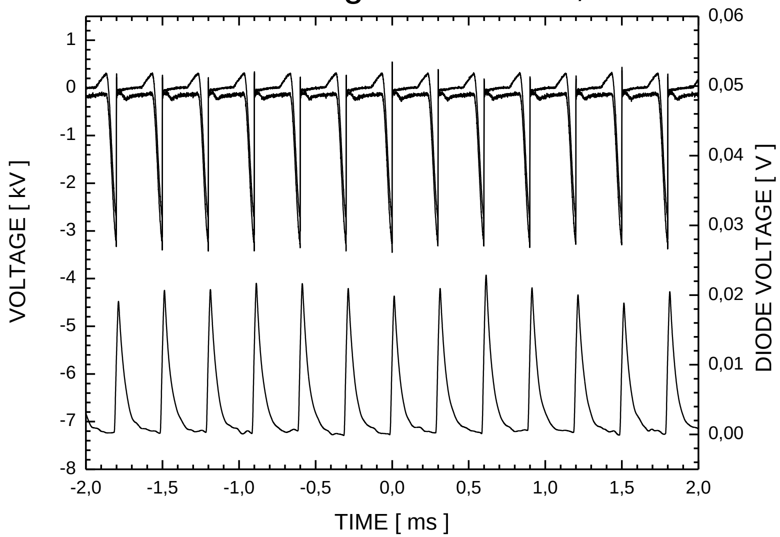
$$L_{peak} = \frac{f\,E_{in}\,CE}{\zeta\,\pi\,r_{1/2}^2}$$

- f (repetition rate) : 3.3 kHz
- E_{in} (pulse energy) : 6.0 J
- CE (conversion eff.) : 0.3 %/2πsr
- ζ (profile factor) : 5.8
- $r_{1/2}$ (radius) : 155 µm

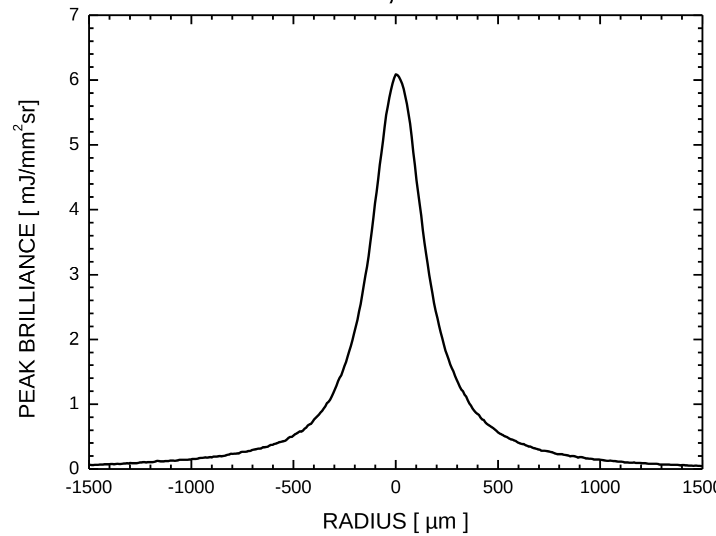
© Fraunhofer ILT

Demonstration of 21 W/(mm²sr)

Diode and voltage for 3.3 kHz, 6.0J



Profile for 3.3 kHz, 6.0J



$$L_{peak} = \frac{f\,E_{in}CE}{\zeta\,\pi\,r_{1/2}^{2}}$$

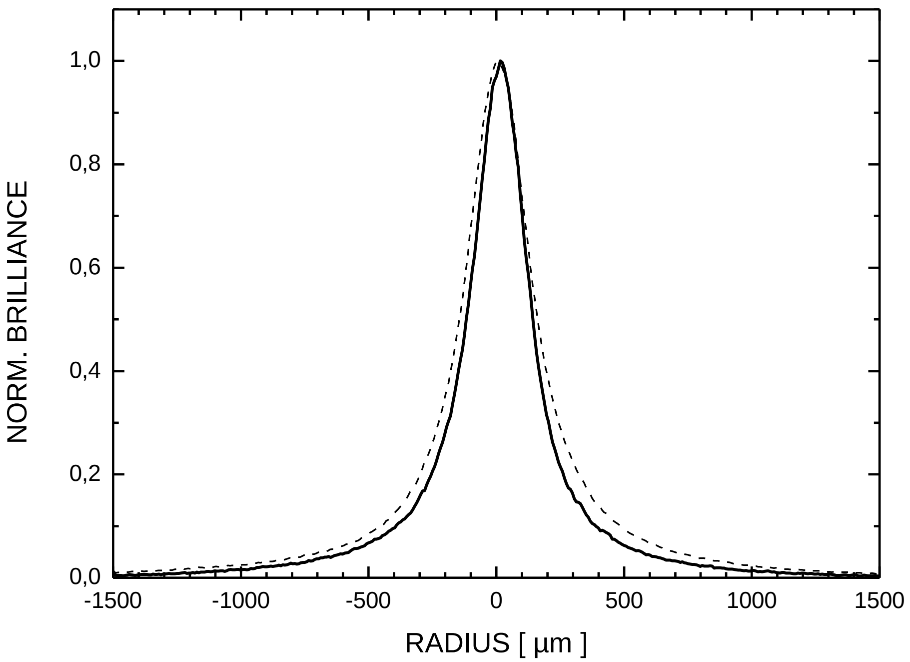
- f (repetition rate) : 3.3 kHz (2.5 kHz)
- E_{in} (pulse energy) : 6.0 J (7.0 J)
- CE (conversion eff.) : 0.3 %/2πsr (0.4 %/2πsr)
- ζ (profile factor) : 5.8 (4.8)
- $r_{1/2}$ (radius) : 155 µm (180 µm)

22.4 W/mm²sr

© Fraunhofer ILT

Scaling Potential >50 W/(mm²sr)

260 µm diameter source profile (full) and
profile from 21 W/mm²sr demonstration (dotted)



- estimation of achievable brilliance by multiplying realistic and already demonstrated best of parameters
- experience with previous system: gas flow conditions is the key optimization parameter

20 kW

0.53 %

$$L_{peak} = \frac{f\,E_{in}\,CE}{\zeta\,\pi\,r_{1/2}^2} = 70.6\,\frac{W}{mm^2 sr}$$

4.5

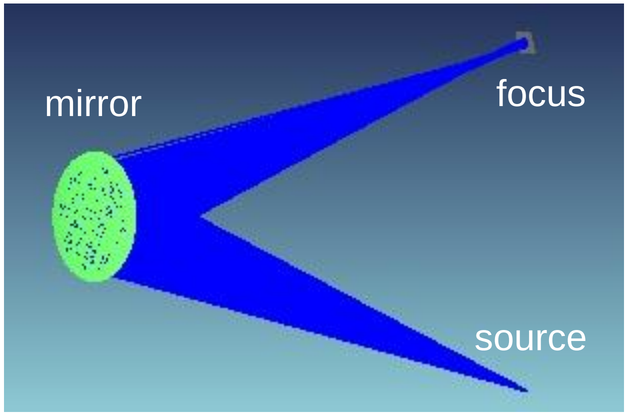
130 µm

© Fraunhofer ILT

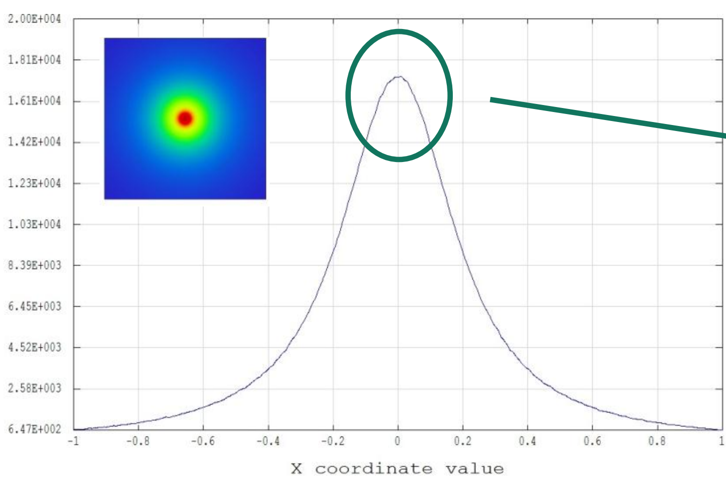
Fraunhofer ILT

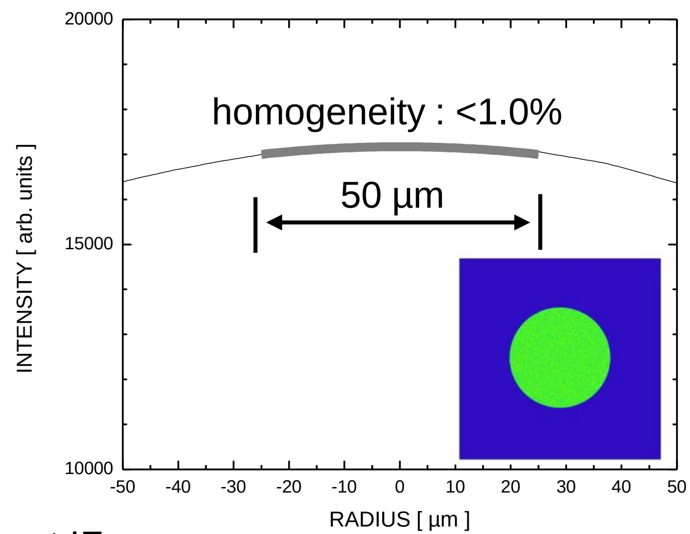
Considerations on Source-Collector-Module

Normal Incidence collector (Ray Tracing)



- example for source-collector-module with typical distance: ~1m source-mirror and mirror-focus
- relaxed requirements for debris-mitigation
- homogeneous illumination of sample over ~50 µm “easy” to achieve





Intensity profile at IF

© Fraunhofer ILT

Fraunhofer ILT

Conclusions

- next discharge source has been taken in operation at ILT
- technical base is status of development together with Philips EUV
- new system is more compact and covers a larger parameter range
- work on brilliance scaling just has started
- demonstration of **21 W/(mm^2 sr)** into 2%b.w. for 13.5 nm at 20 kW input power
- optimization potential for **>50 W/mm^{2}sr** based on experimental data has been identified

© Fraunhofer ILT

Acknowledgements

- Markus Benk (currently at CXRO in Berkeley)
- Jochen Vieker
- Federal State NRW, Germany for financial support

© Fraunhofer ILT